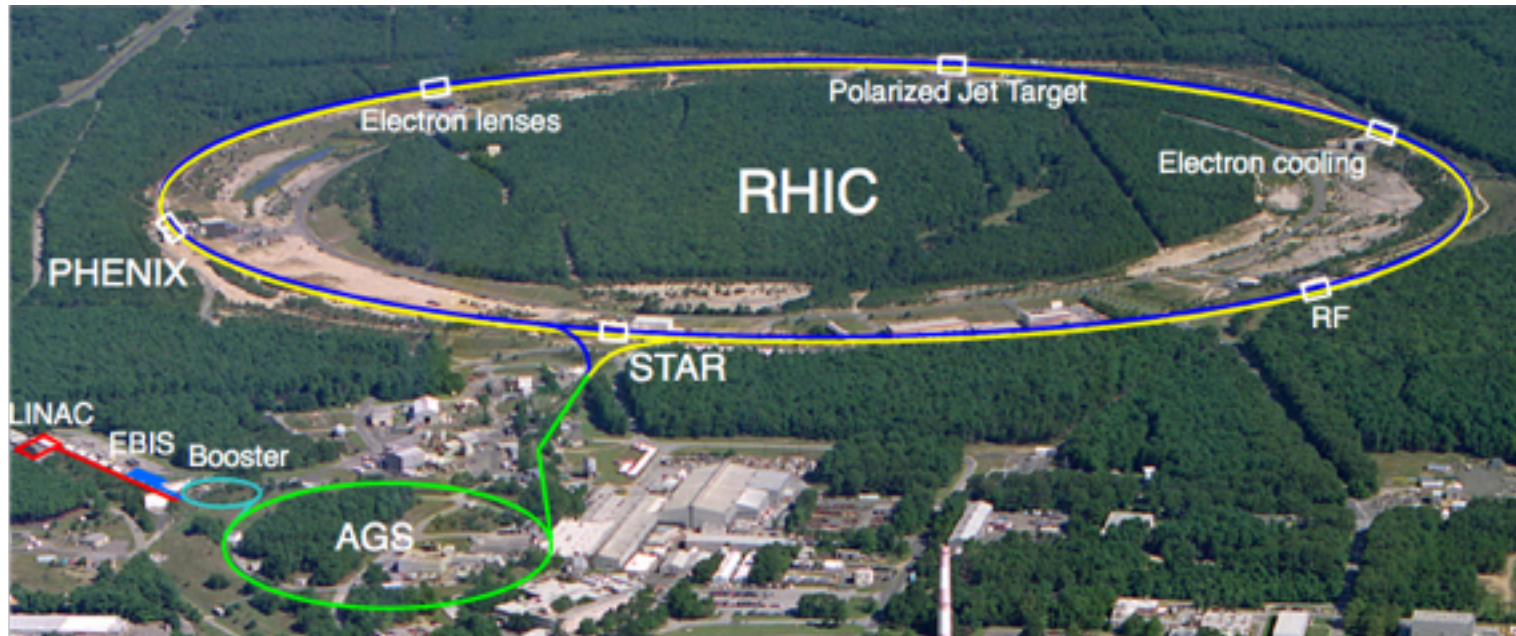


RHIC S&T Overview 2016

Berndt Mueller



Agenda

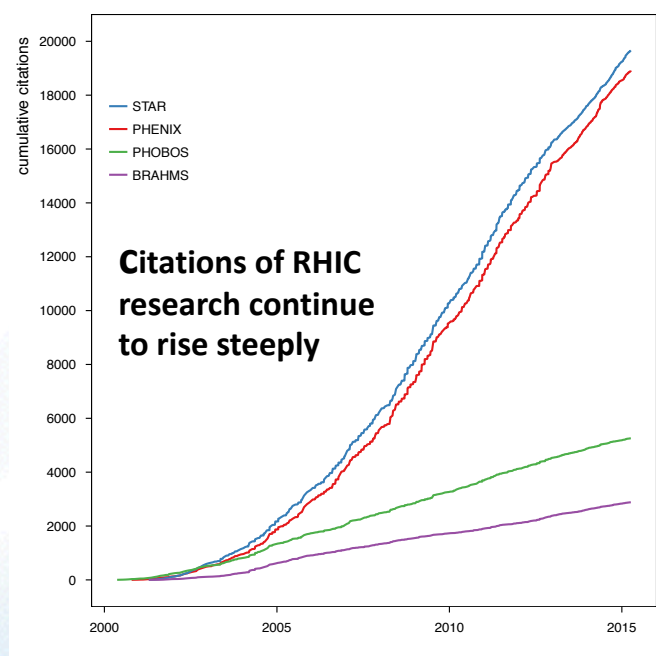
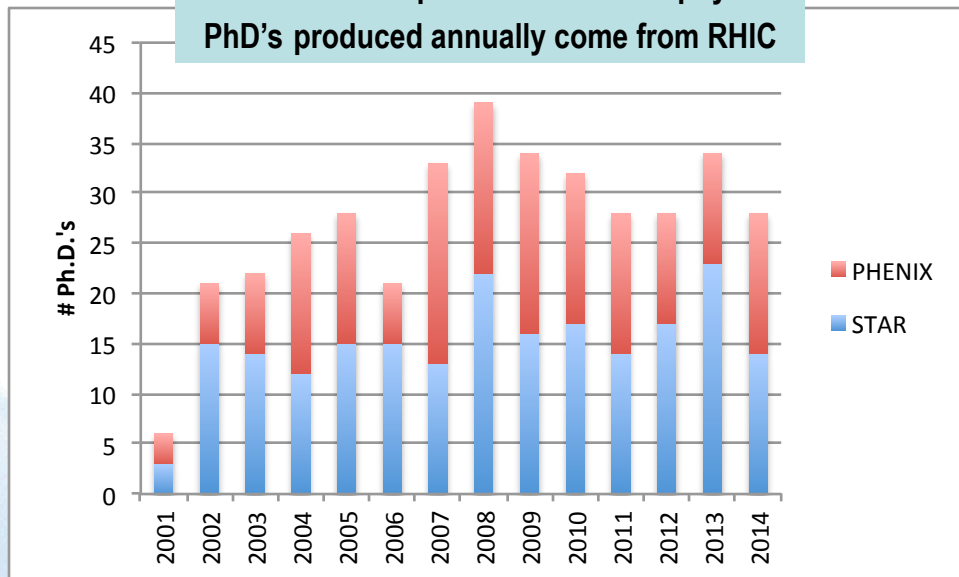
- **Recent (Run 14-16) highlights**
- **Plans for 2017-20 RHIC Runs**
- **Status of iTPC, LEReC, sPHENIX upgrades**
- **Long-term vision & transition to eRHIC**
- **Laboratory support**
- **Synergies with non-NP programs**
- **Response to 2014 recommendations**

Recent Highlights

RHIC: Productivity and Impact (update)

Collaboration	Total # Refereed Papers	Total # Citations for Ref'd Papers	# PRL's	# Citations for 2005 White Paper	Position Among Most Cited NP Papers 2001-14	# Papers with >250 Citations
PHENIX	142	18,812	66	1,923	4	17
STAR	171	19,673	65	2,008	3	19
PHOBOS	39	4,999	15	1,488	5	1
BRAHMS	22	3,477	10	1,462	6	3
Total	374	46,961	156	5,943	4 in top 10	40

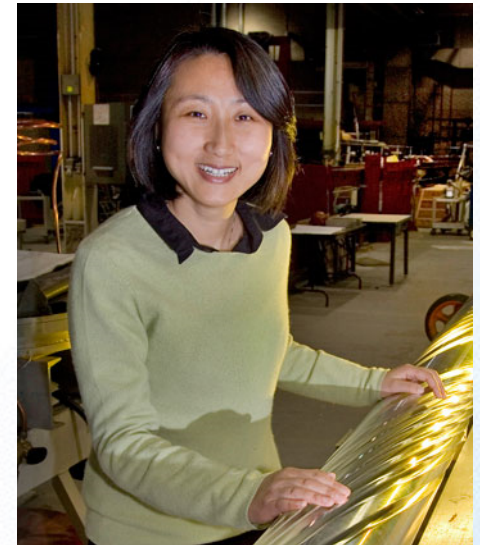
About 40% of experimental nuclear physics
PhD's produced annually come from RHIC



RHIC related awards (2015-16)

- Ernest O. Lawrence Award:
 - Mei Bai
- APS Bonner Prize:
 - M. Gyulassy & H. Wieman
- APS Feshbach Prize:
 - L. McLerran
- BNL S&T Award:
 - Flemming Videbaek
- ATLAS Thesis Award
 - Dennis Perepelitsa
- Excellence Professor (U Heidelberg)
 - Raju Venugopalan

Mei Bai



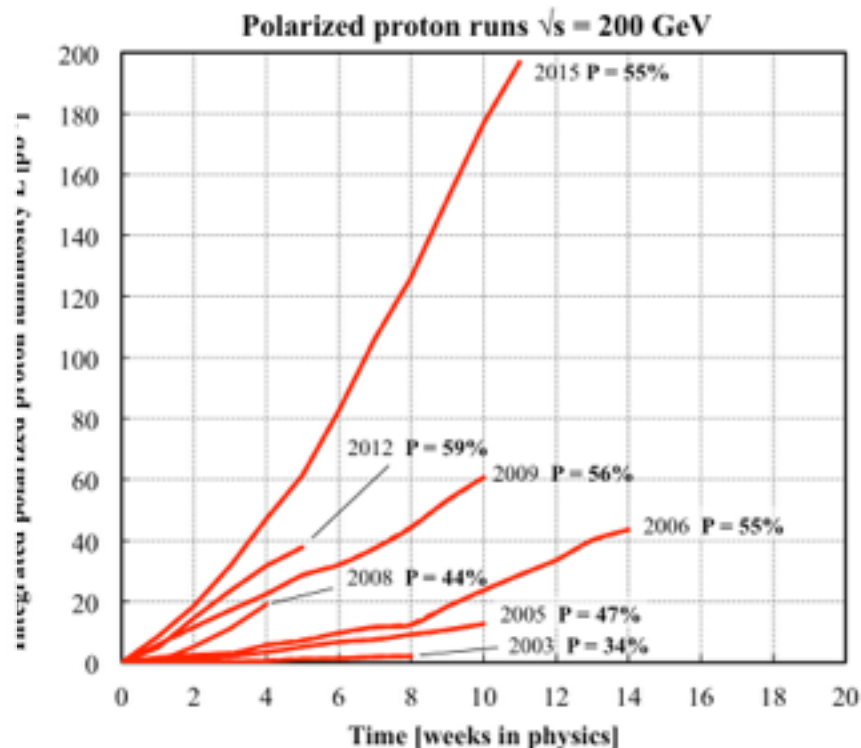
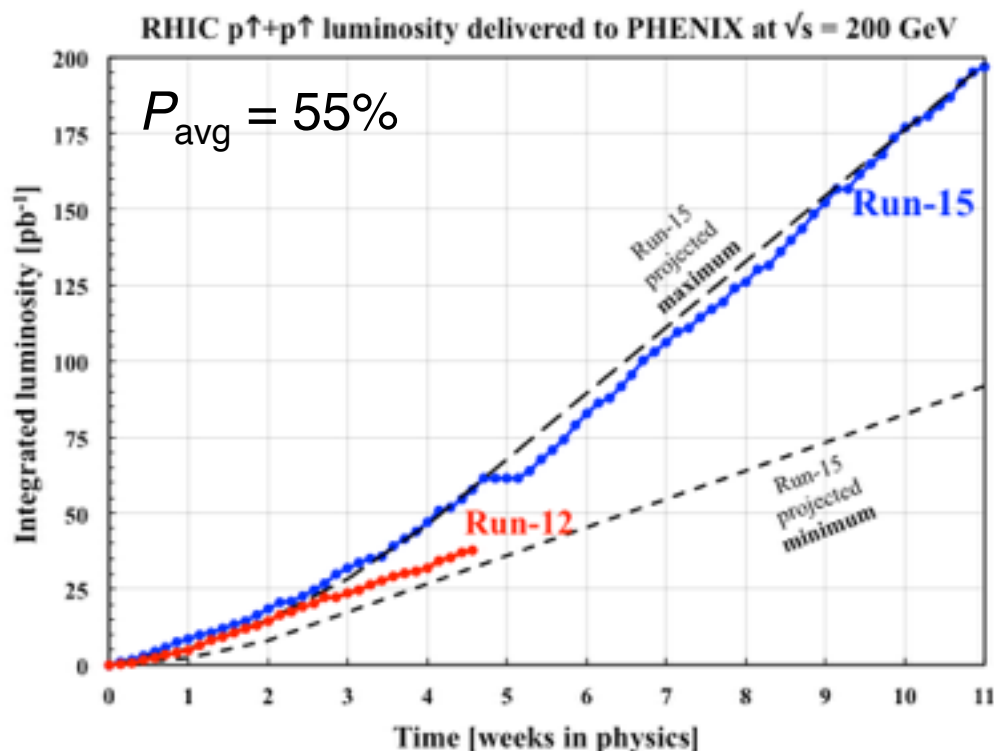
Presented today
at DOE HQ

RHIC sets new records ... (update)

Run-15 $p\uparrow+p\uparrow$ at $\sqrt{s} = 200$ GeV

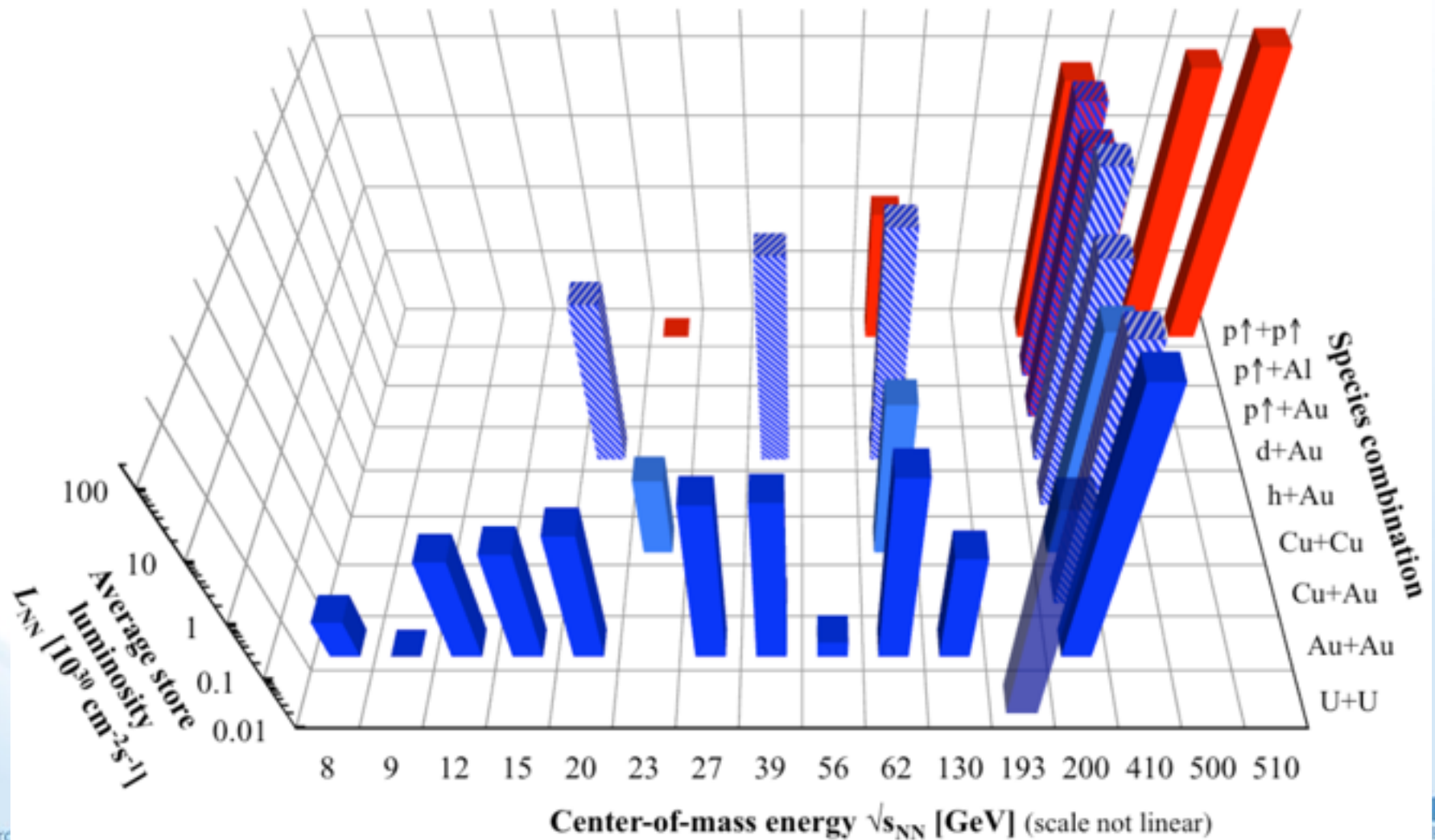
$L = 25 \text{ pb}^{-1}/\text{week}$ (2.7×2012)

Run-15 integrated luminosity at $\sqrt{s} = 200$ GeV exceeds sum of all previous runs



You want it - you can have it!

RHIC energies, species combinations and luminosities (Run-1 to 16)

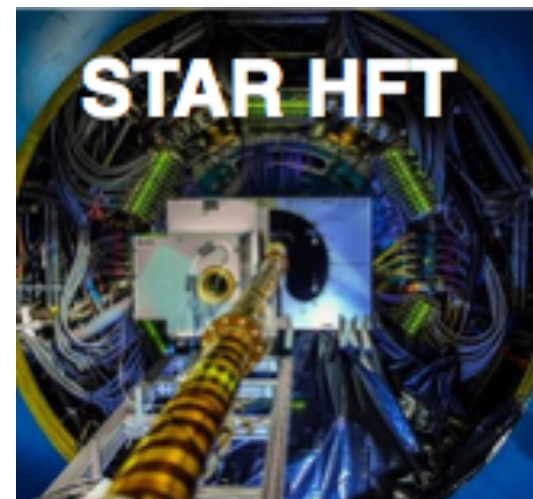
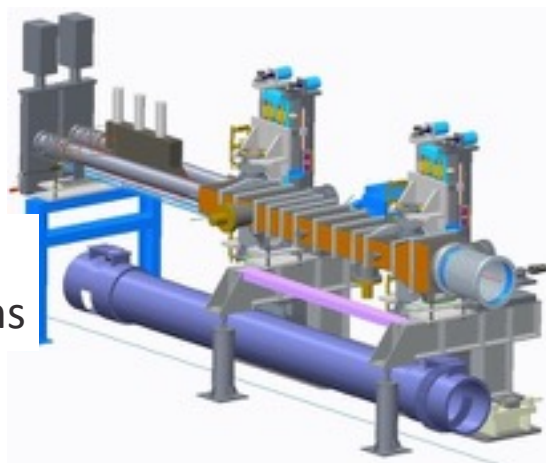


Recent Detector Upgrades

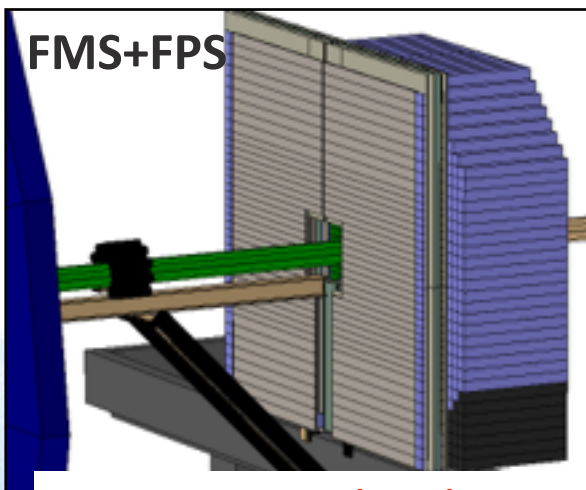
Trigger/DAQ x2 throughput

Roman Pots (2015)

Tag diffractive protons



FMS+FPS

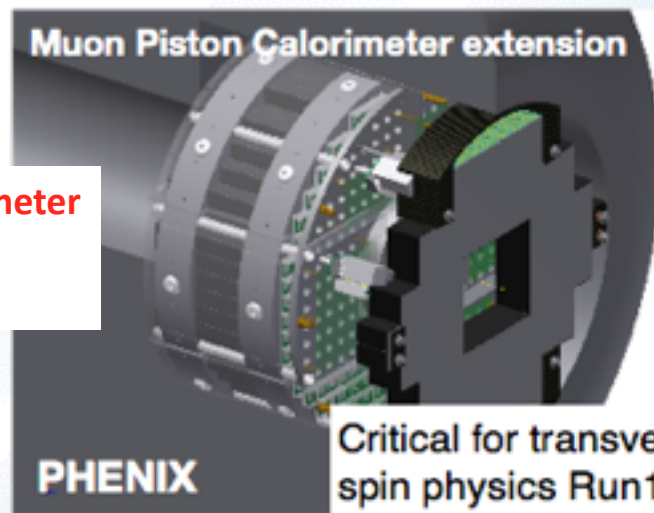


FMS + pre-shower (2015)

A_N photon, jets, Drell-Yan; ridge, fluctuation, spectators

Muon Piston Calorimeter Extension (2015)

Forward photons ID



Run 16 & 17 plans

PAC recommendations (in order of priority):

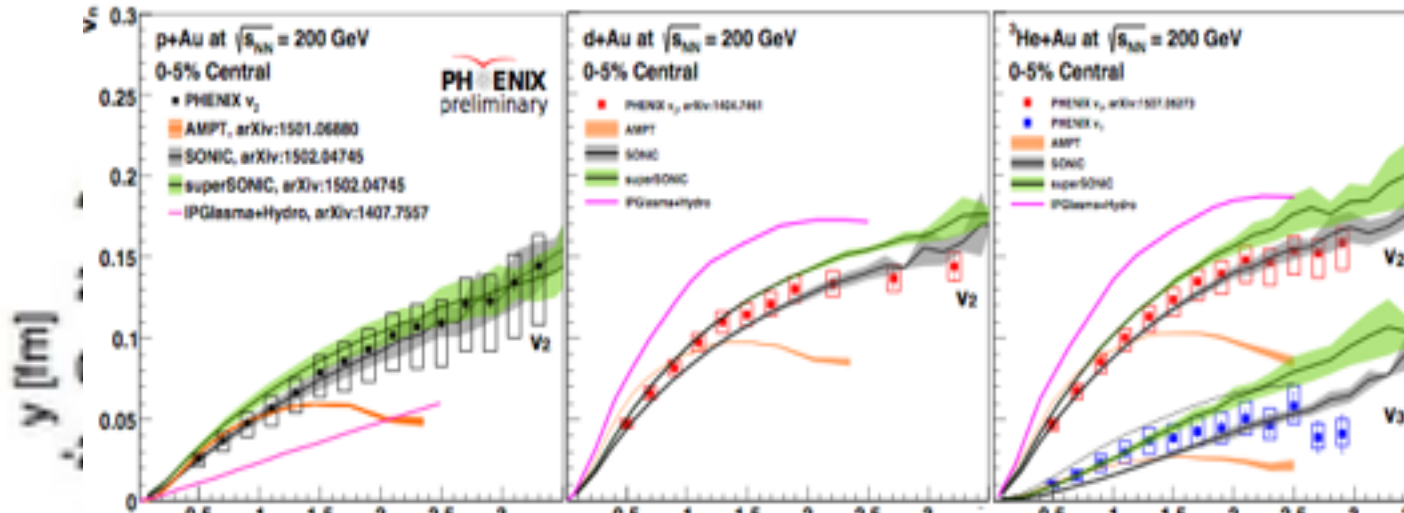
Run-16

- Au+Au at 100 GeV, 10 weeks
56 MHz SRF, further increase in bunch intensity
- Au+p \uparrow (or p \uparrow +Au or d+Au) at 100, 31.2, 20, 10 GeV/nucleon, 5 weeks
PHENIX / STAR protection, task force set up
- p \uparrow +p \uparrow at 31.2 GeV, 2 weeks
- Au+Au at 31.2 GeV, up to 4 weeks

Run-17

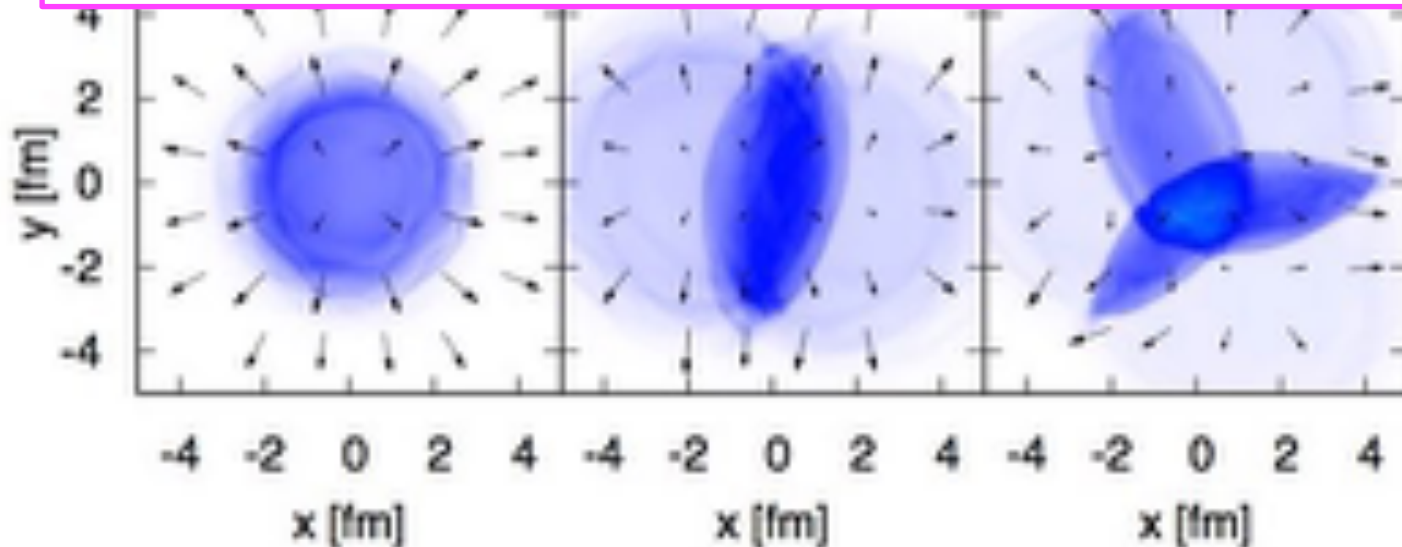
- p \uparrow +p \uparrow at 255 GeV, ≥ 11 weeks
- Ru+Ru and Zr+Zr ($A = 96$ in both cases)
- p \uparrow +p \uparrow at energies matching p+Au (d+Au) energy scan

Tiny drops of QGP?



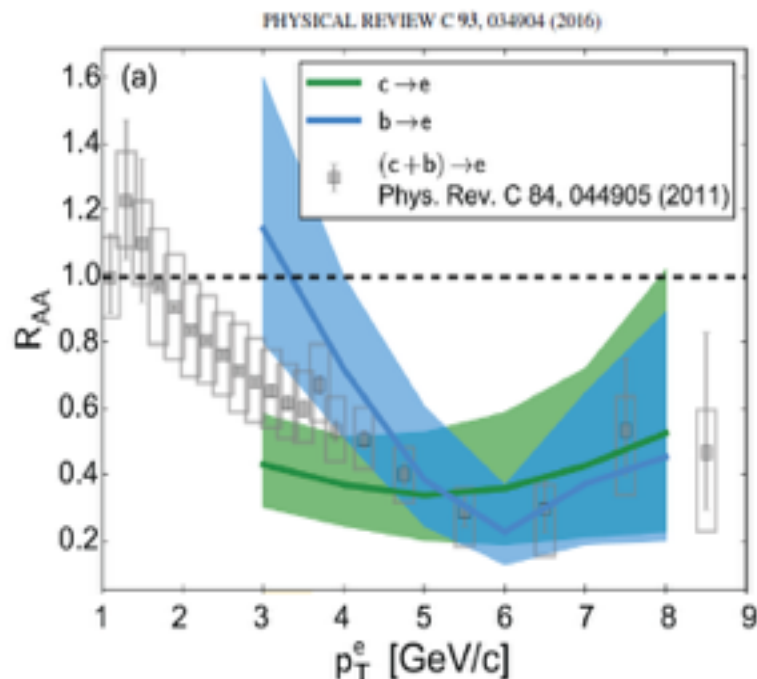
Data-Theory comparison confirms hydrodynamic collective flow

An opportunity for heavy ion theory being tackled now



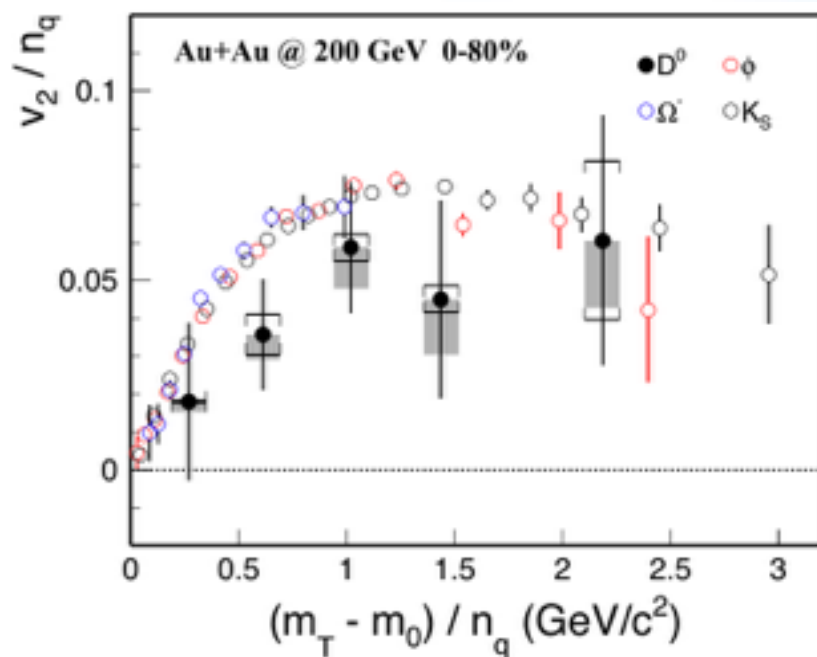
Final state

Heavy Quark Transport in the QGP



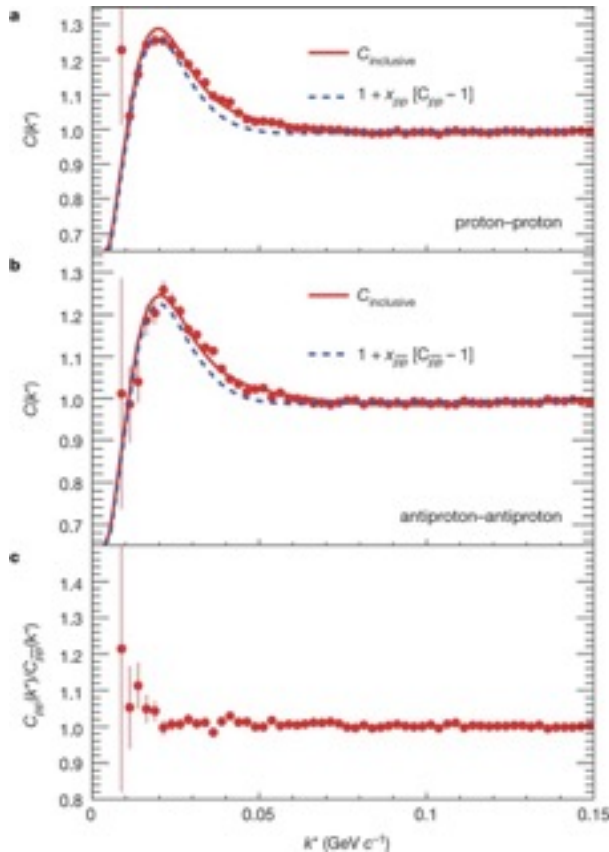
Both b and c quarks are suppressed at large p_T

Hadrons containing c quarks show signs of collective flow

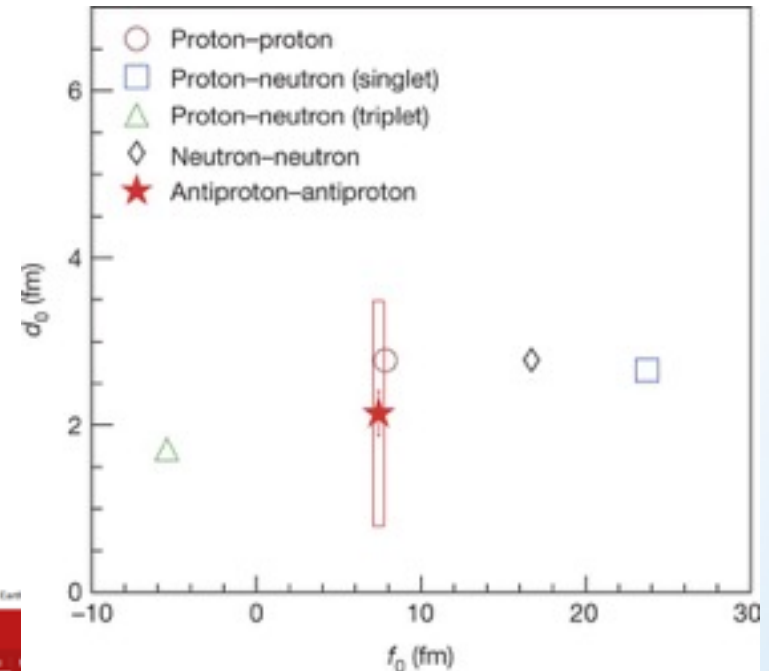


Small heavy quark diffusion constant confirms strong coupling of QGP at different scale from hydrodynamics.

Interaction between two antiprotons



[Nature 527, 345 \(2015\)](#)

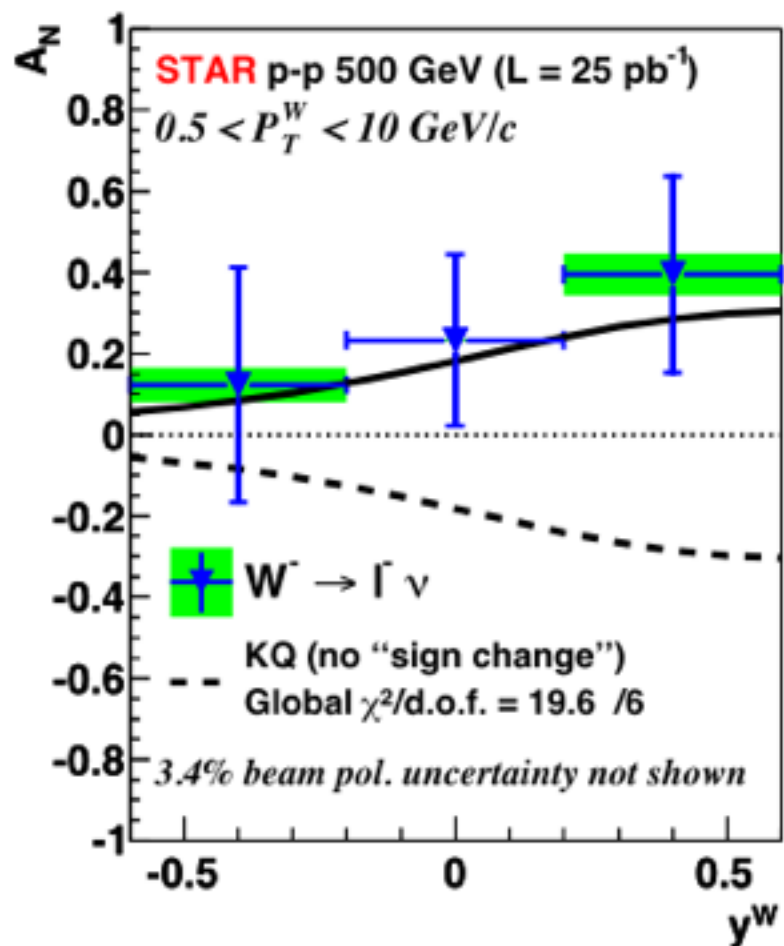
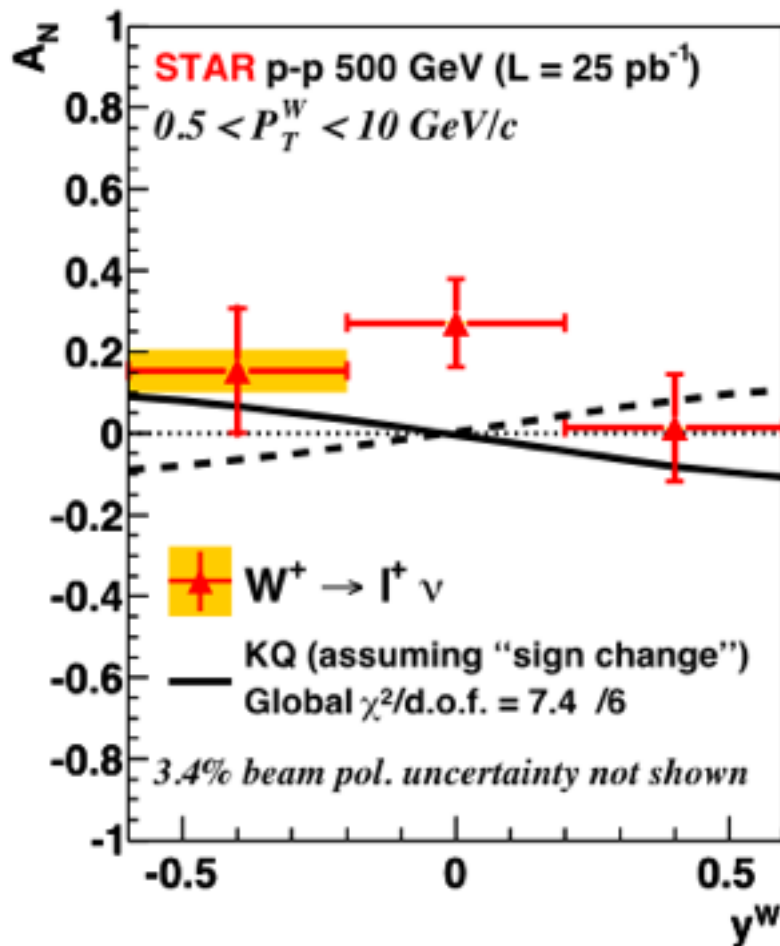


By applying a technique similar to Hanbury-Brown and Twiss intensity interferometry, we show that the force between two antiprotons is attractive.

We report two key parameters that characterize the corresponding strong interaction: the scattering length and the effective range of the interaction

W Sivers function (Run-17)

Phys. Rev. Lett. 116 (2016) 132301



Chiral Magnetic wave

Editors' Suggestion

Observation of Charge Asymmetry Dependence of Pion Elliptic Flow and the Possible Chiral Magnetic Wave in Heavy-Ion Collisions

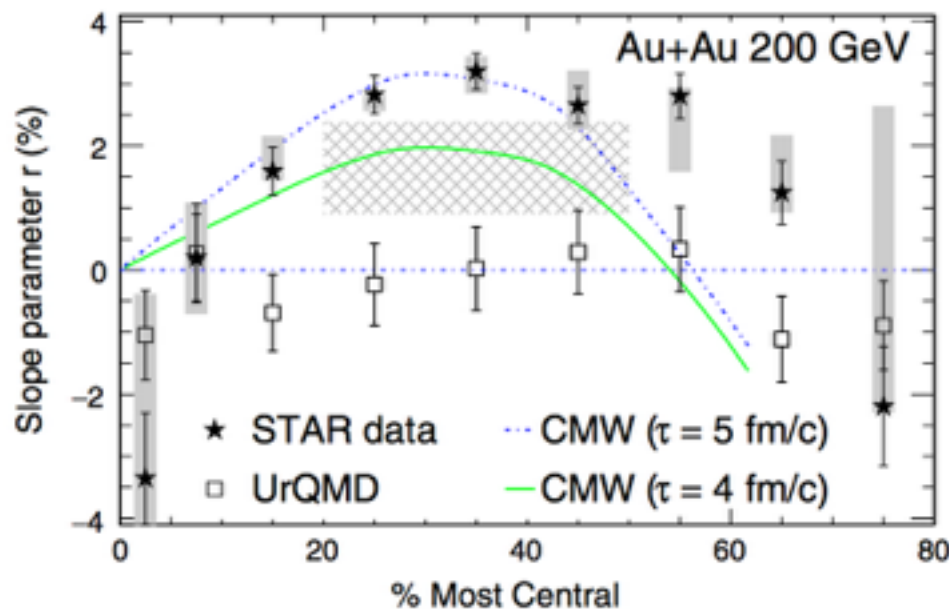
L. Adamczyk *et al.* (STAR Collaboration)

Phys. Rev. Lett. **114**, 252302 (2015) – Published 26 June 2015



A possible signature of chiral symmetry restoration, in the form of a chiral magnetic wave in the quark-gluon plasma, has been observed in heavy-ion collisions at RHIC.

[Show Abstract +](#)



- STAR has published a few papers on possible Chiral Magnetic Effect and potential background
- Implication beyond our field
- Continue research:
 - U+U collisions
 - BES I results on CME
 - BES II with more statistics
 - Chiral Magnetic Wave
 - Chiral Vortical Effect

Future Science 2017-20

Run-17 Plan

- High luminosity 510 GeV transverse polarized p+p run (13 weeks)
- Study scale evolution of the Sivers effect in W-boson production; possibly confirm sign change of the Sivers effect relative to DIS
- Proof of Principle test of coherent electron cooling (1 week)

Run-18 Plan

- Isobar system (^{96}Ru - ^{96}Zr) run (8 weeks)
- Critical signature of Chiral Magnetic Effect

Strongly endorsed by 2016 RHIC PAC.

New Questions

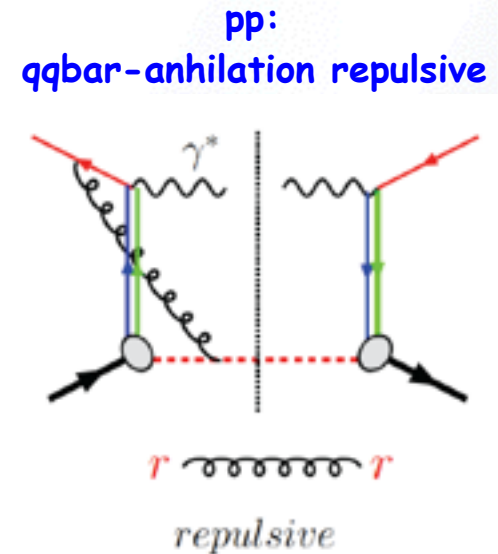
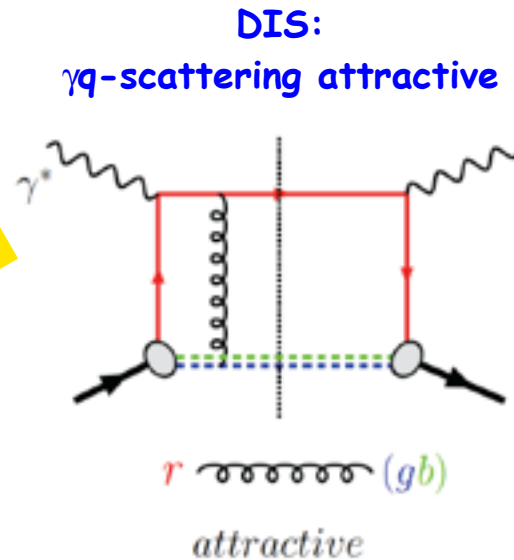
- Do the **initial conditions** for the hydrodynamic expansion contain unambiguous information about saturated gluon fields in nuclei?
- What is the smallest collision system that behaves **collectively**?
- What does the **QCD phase diagram** look like? Does it contain a **critical point** in the HG-QGP transition region? Does the HG-QGP transition become a **first-order phase transition** for large μ_B ?
- What is the **structure of the strongly coupled QGP** at varying length scales? What makes it a liquid?
- What do Upsilon states tell us about quark **deconfinement** and **hadronization**?
- What do transversely polarized protons tell us about the **coupled spin-momentum dynamics** of QCD at different scales?

Transverse polarized p+p collisions

Access the dynamic structure of protons:

- **Test and confirm QCD structure of color spin interactions**
 - **Non-universality of transverse momentum dependent functions**
 - $\text{Sivers}_{\text{DIS}} = - \text{Sivers}_{\text{pp}}$
 - Observable: A_N for Drell-Yan and $W^{+/-}$ production

Achieves
NP Performance
Milestone HP13
in Run 17?



- **Test scale evolution of transverse momentum dependent functions**
 - Observable: compare magnitude of A_N for Drell-Yan and $W^{+/-}$
Scale: DY: $Q^2 \sim 16 \text{ GeV}^2$ $W^{+/-}$: $Q^2 \sim 6400 \text{ GeV}^2$

Probing Chiral Symmetry with Quantum Currents

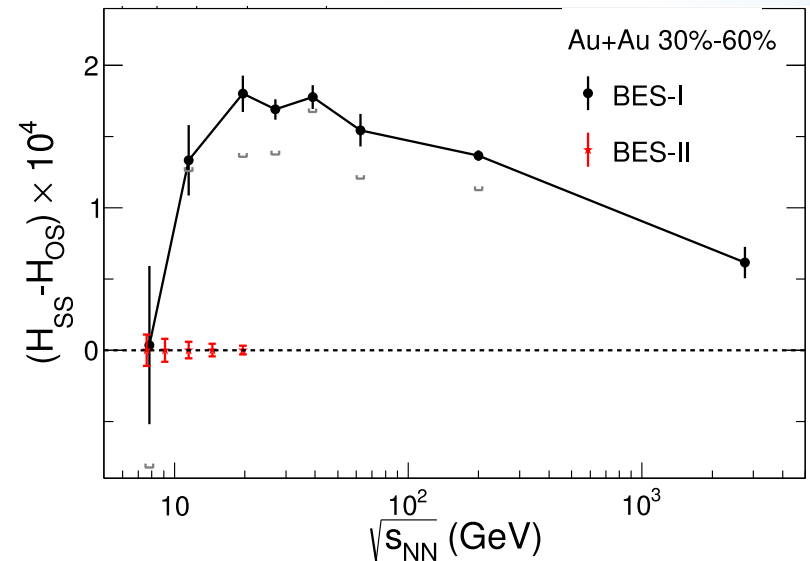
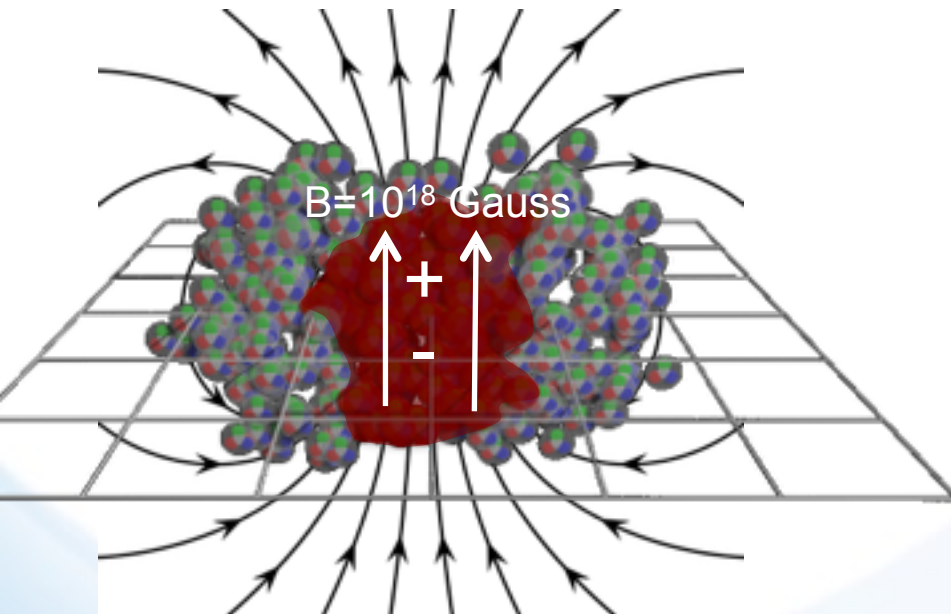
The chiral anomaly of QCD creates differences in the number of left and right handed quarks.

A similar mechanism in the electroweak theory is likely responsible for the matter/antimatter asymmetry of our universe

In a chirally symmetric QGP, this imbalance can create charge separation along the magnetic field (chiral magnetic effect – just discovered in CM at BNL)

charge separation

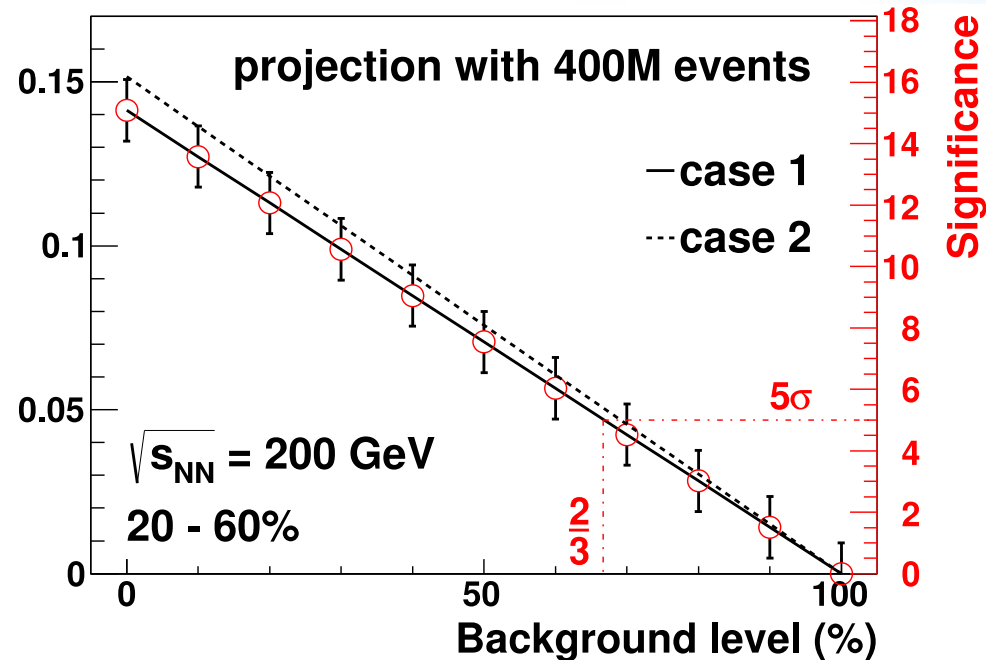
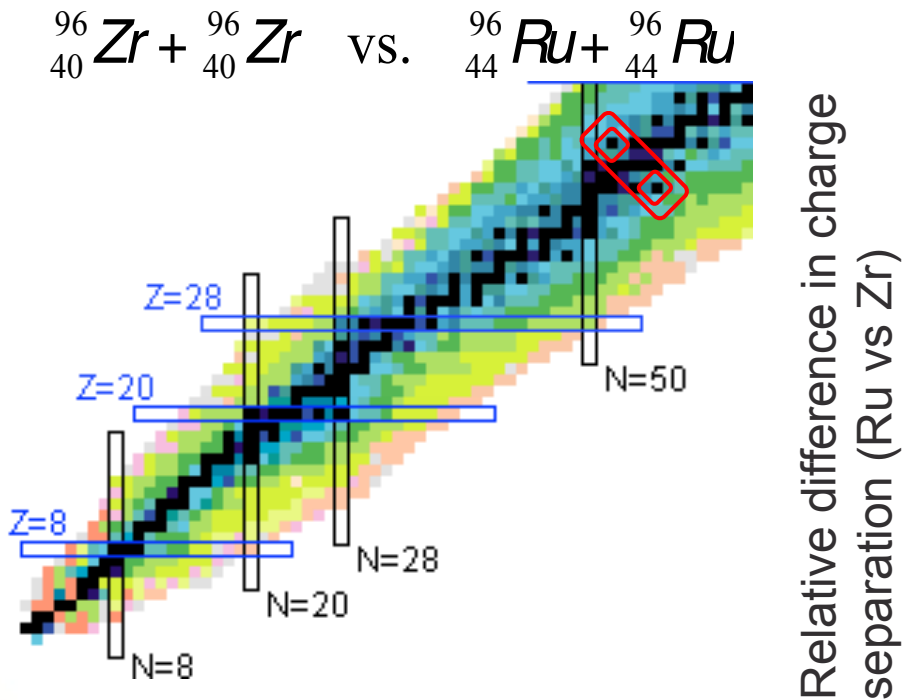
observed at all but the lowest energy



But models with magnetic field-independent flow backgrounds can also be tuned to reproduce the observed charge separation.

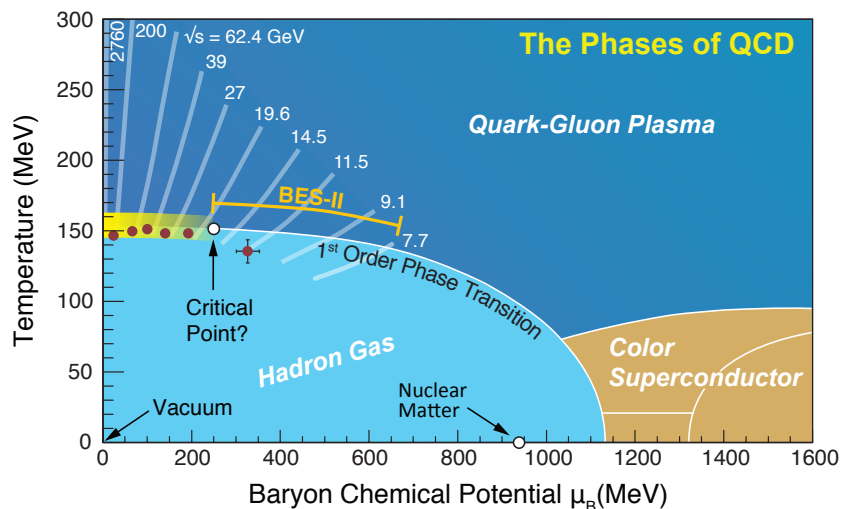
Probing Chiral Symmetry (Run-18)

Current understanding: backgrounds unrelated to the chiral magnetic effect may be able to explain the observed charge separation

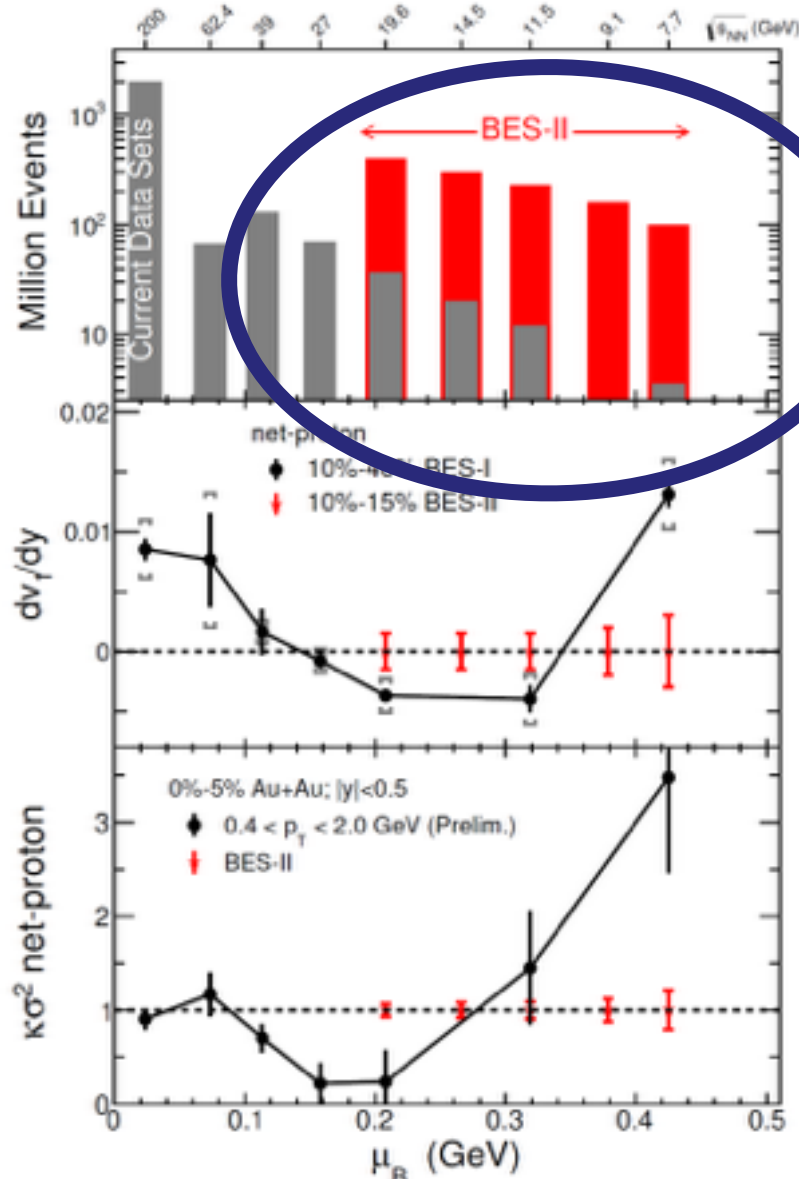
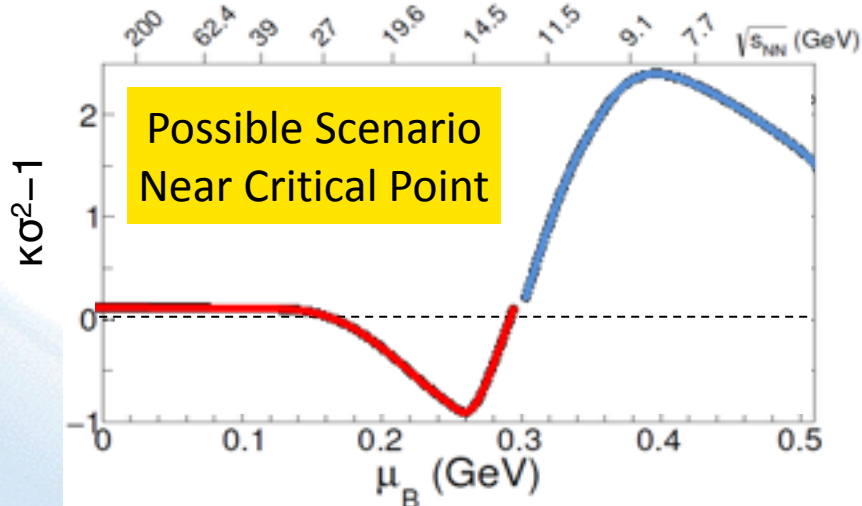


Isobar collisions will tell us what fraction of the charge separation is due to CME to within $\pm 6\%$ of the observed signal

Toward critical fluctuations



Model independent structure of net baryon number kurtosis



iTPC, LEReC, sPHENIX

STAR Upgrades and Performance Enhancements

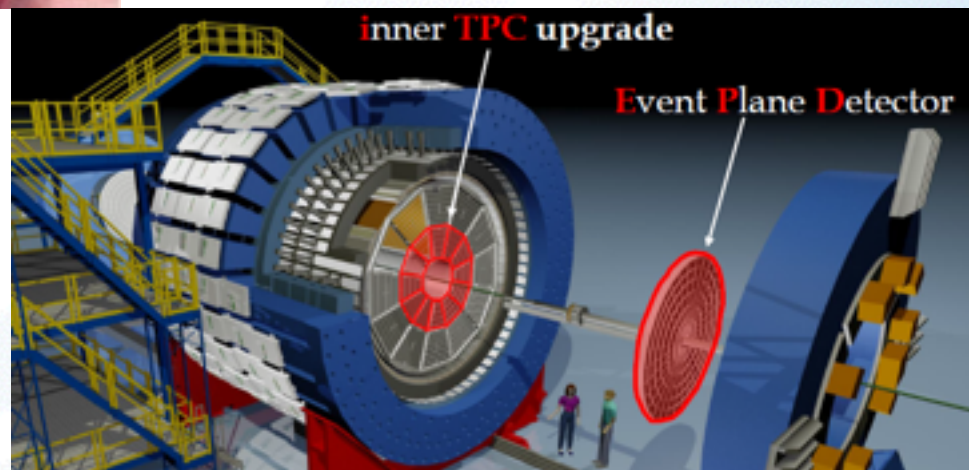


iTPC upgrade (2018)

- Replace inner TPC Sectors
- Extend rapidity coverage
- Better particle ID
- Extend low p_T coverage

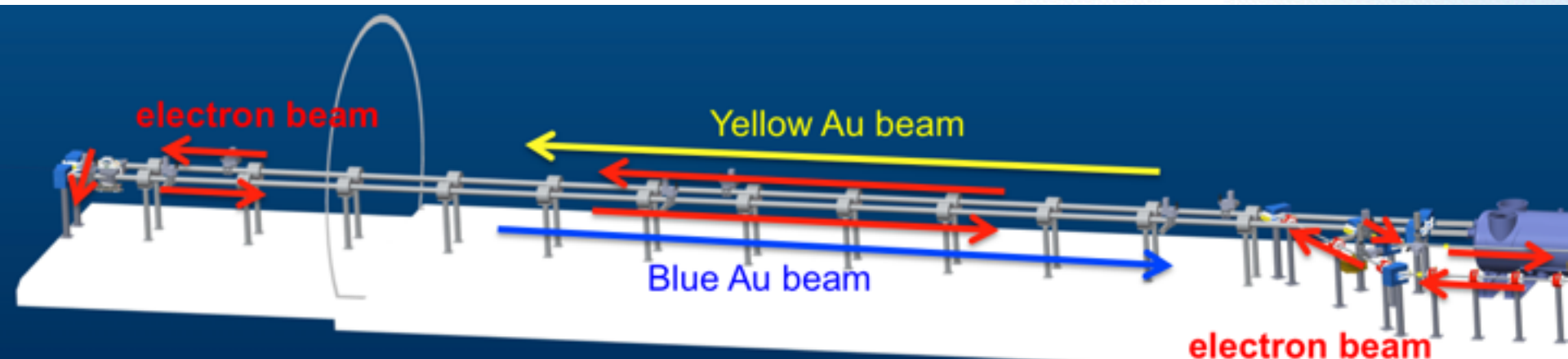
Event Plane Detector (2018)

- Improved Event Plane Resolution
- Centrality definition
- Improved trigger
- Background rejection

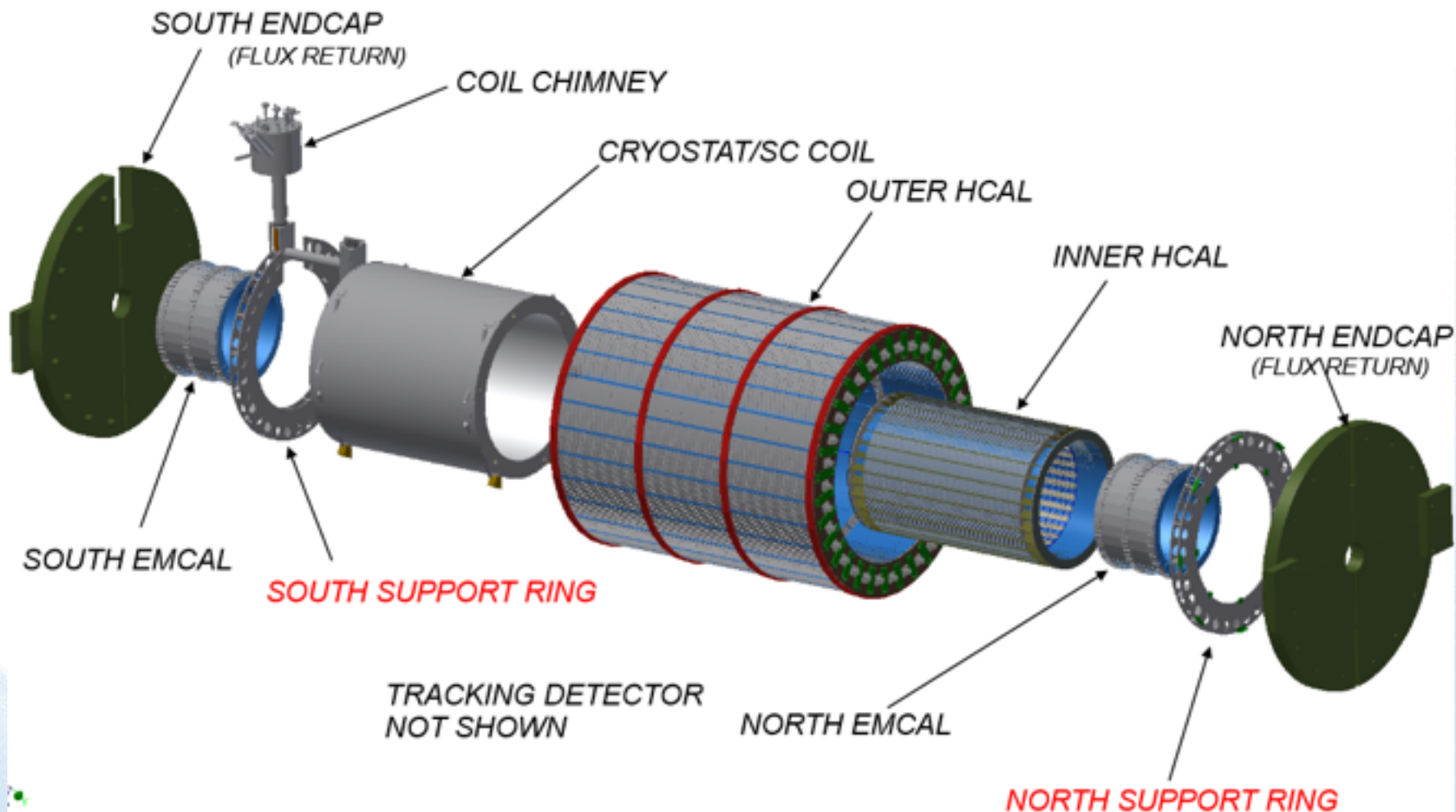


Low Energy e-Cooling for BES-II

- Cooling of low energy heavy ion beams (3.8–5.0 GeV/n) with bunched electron beam increases luminosity by up factor 10
- Enables a QCD critical point search with a high statistics Beam Energy Scan
- Use Cornell DC electron gun and existing SRF cavity for cost effectiveness
- Cost: \$8.3M
- Complete installation in 2018, use in low energy RHIC runs in 2019-20



sPHENIX (update)



sPHENIX Status

sPHENIX detector collaboration:

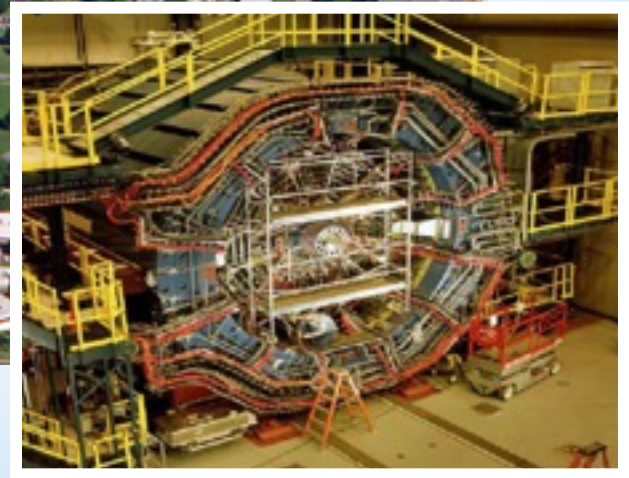
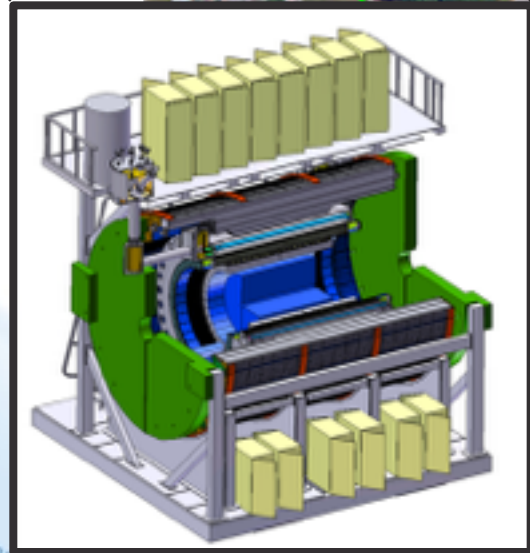
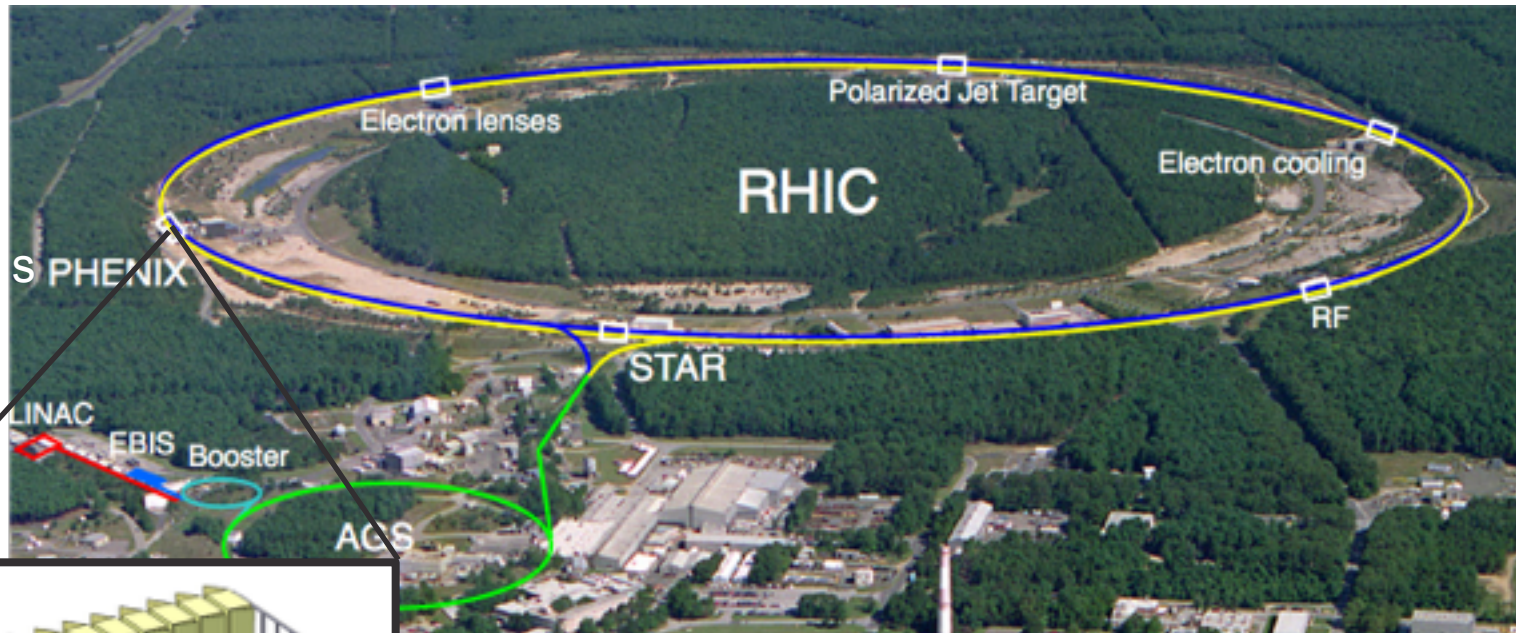
- First collaboration meeting December 2015 at Rutgers
- Collaboration spokesperson team (Roland/Morrison) elected
- Second collaboration meeting May 2016 at BNL

sPHENIX Project progress:

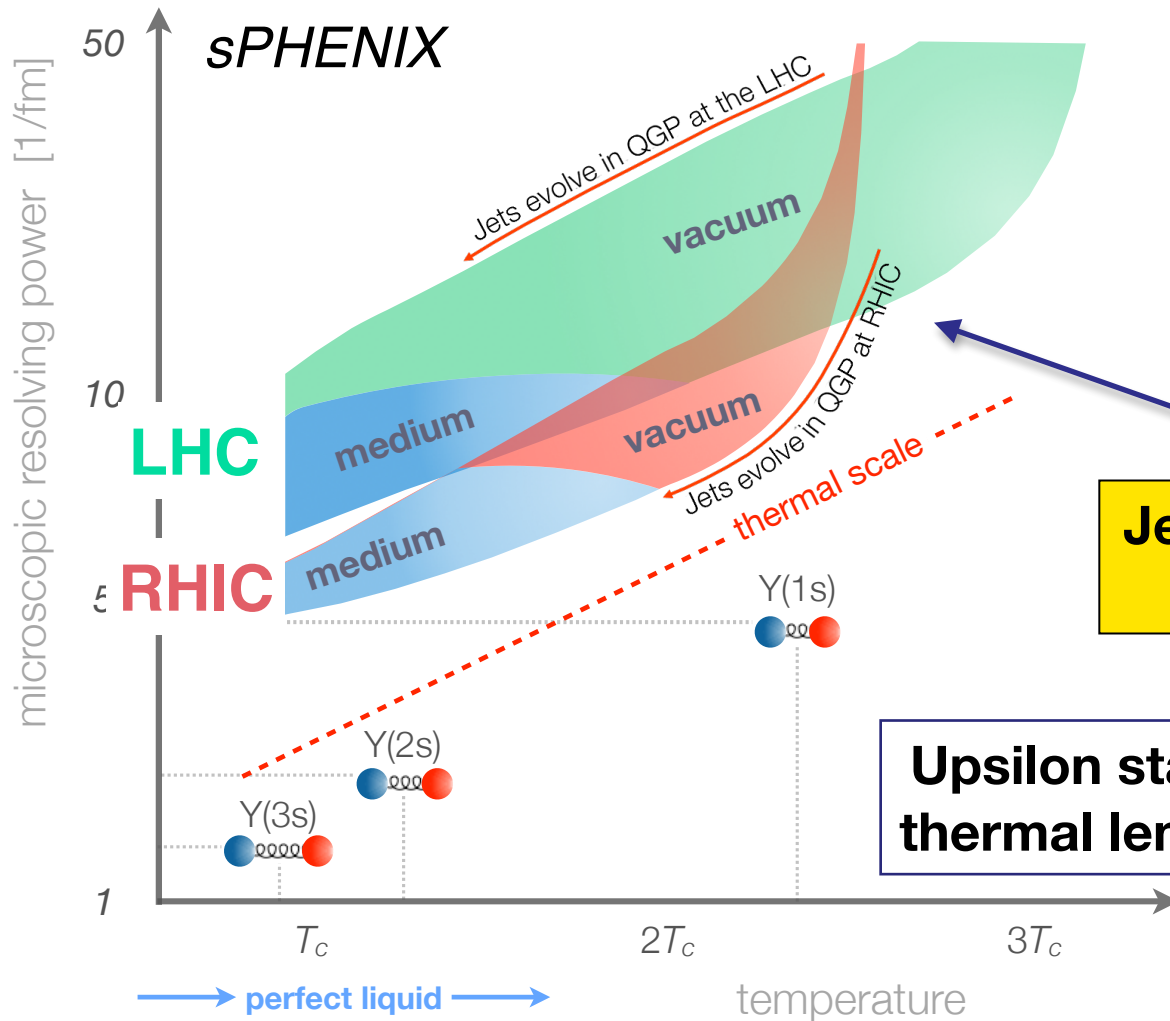
- Science case recommended in new NSAC LRP
- Successful science review by DOE April 30, 2015
- PMG advising ALD meets bi-weekly
- Preliminary CDR completed
- Director's cost and schedule review November 2015
- Removal and Repurposing of unneeded PHENIX components begun
- Re-scoping exercise by Collaboration completed
- Tracker review scheduled for September 2016

Long term vision

The RHIC Facility in 2022



Probing scales in the medium



How does the perfect fluidity of the QGP emerge from the asymptotically free theory of QCD?

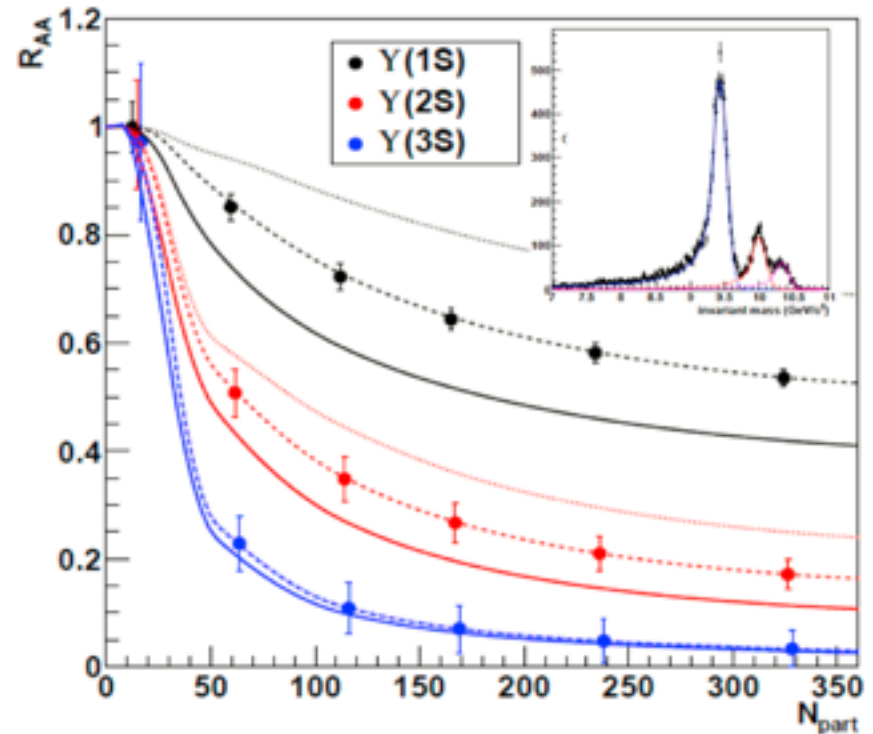
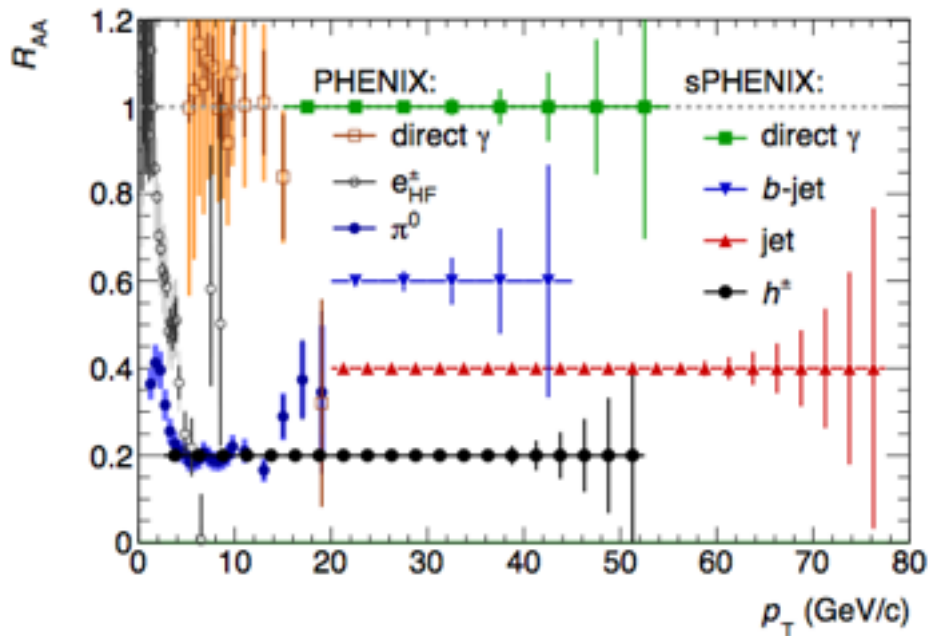
Jets probe sub-thermal length scales

Υ states probe thermal length scales

Jets & Upsilon states

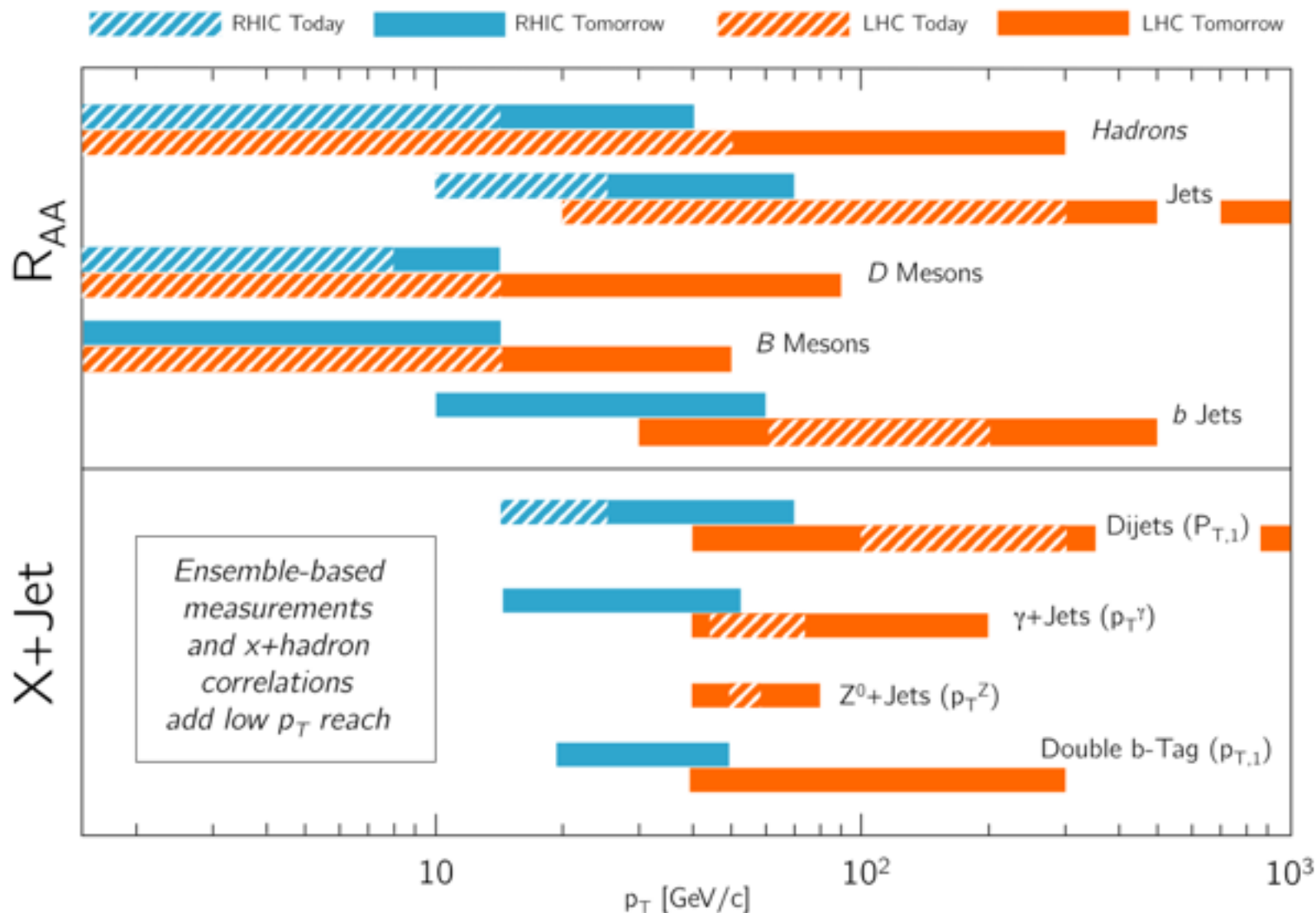
sPHENIX
capabilities

**Complete calorimetric
jet spectroscopy**



**Completely resolved
Upsilon spectroscopy**

RHIC & LHC complementarity



Proposed run schedule for RHIC

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2016	High statistics Au+Au d+Au beam energy scan	Complete heavy flavor program First measurement of Λ_c Collectivity in small systems	Coherent e-cooling test I
2017	High statistics Pol. p+p at 510 GeV	Transverse spin physics	Coherent e-cooling test II
2018	$^{96}\text{Zr}+^{96}\text{Ru}$ at 200 GeV Au+Au at 27 GeV ?	Establish chiral magnetic effect	Low energy e-cooling upgrade
2019-20	7.7-20 GeV Au+Au (BES-2)	Search for QCD critical point and onset of deconfinement	STAR iTPC upgrade EPD upgrade
2021	No Run ?		sPHENIX installation
2022-??	200 GeV Au+Au with upgraded detectors Pol. p+p, p+Au at 200 GeV	Jet, di-jet, γ -jet probes of parton transport and energy loss mechanism Color screening for different quarkonia	sPHENIX Forward upgrades ?
mid-2020s	Transition to eRHIC ?	Gluon structure of p and A	Upgrade to “ePHENIX” ?

What RHIC will deliver

■ Campaign 1 (2014-17):

- QCD equation of state at $\mu_B \approx 0$
- Precision measurement of $\eta/s(T \approx T_c)$
- Measurement of heavy quark diffusion constant $D_{c/b}$
- Measurement of nucleon/nuclear granularity at small x
- Δg , flavor dependence of spin in the quark sea
- Origin of single spin asymmetries

■ Campaign 2 (2018-20):

- QCD equation of state at $\mu_B > 0$
- Discovery of the QCD critical point, if within range
- Discovery of QCD anomaly driven transport in chiral QGP

■ Campaign 3 (2022-??):

- Precision measurement of $q^*(T \approx T_c)$ and $e^*(T \approx T_c)$
- Length scale where the QGP becomes a liquid
- Many additional insights we can't even anticipate yet !

Laboratory Support Synergies

Lab/other investments

- LDRD / PD support for NPP increased from \$2.7M (FY14) to \$8.1M (FY16)
- Total LDRD / PD support for RHIC/eRHIC: \$3.9M ???
- Lab support for postdocs in NPP: ~\$500k (FY16)
- Balanced by \$3M reduction in base BNL support for IO
- \$500k/year support for RBRC

Synergies

- Japanese support for RBRC: \$4M/year
- Joint appointments with SBU:
 - D. Kharzeev, J. Jia, V. Litvinenko (50/50)
 - Many unpaid joint appointments
 - JA with Bielefeld (Karsch)
- BLIP (medical isotopes)
- NSRL (NASA funded)
- ATF (accelerator stewardship)
- CASE (SBU)
- Lattice gauge theory (HEP)

Recent actions Previous Recommendations

Recent actions & issues

- Eric Lançon new RACF Director (M. Ernst retired)
- Bill Christie new head of experimental operations in C-AD (Phil Pile retired)
- Ferdinand Willeke new Director of eRHIC R&D
- Thomas Roser also Deputy ALD for Accelerators
- Jianwei Qiu new Nuclear Theory group leader
- Larry McLerran leaves to direct INT
- Offer made to Zhongbo Kang (LANL - 50% RBRC)
- RHIC experimental staff reduced by ~10 to match B/A.
- Task Force on STAR computing formed
- ????

DOE Recommendations 2014

- Evaluate in detail the performance of the HFT, with respect to luminosity-related degradation and establish a detailed plan of operation for run 15 and beyond. Report progress at the DOE HFT quarterly status meetings.
- Prepare a report on detector data collection efficiency, estimating or measuring the contributions to the efficiency reduction. The report should report the expected limit of the average efficiency and the five most important contributors to the efficiency. This report should be submitted to DOE by January 12, 2015.
- BNL is encouraged to resolve the HVAC problem at RACF as soon as possible. Updates on plans and progress should be provided quarterly in regularly scheduled bi- weekly phone conferences with the Office of Nuclear Physics.
- The RACF and the detector collaborations should analyze the processing capacity required to perform the necessary production runs (in units of HS06*years) and compare to the available capacity of RACF. If additional capacity is required, a plan to acquire the necessary capacity by 2018 should be developed. This plan should be submitted to DOE by January 12, 2015.

Summary

- **RHIC is planning a unique forefront science program with continued discovery potential as laid out in NSAC LRP:**
 - Quantify the transport properties of the QGP *near* T_c using heavy quarks as probes
 - Measure gluon and sea quark contributions to proton spin and explore transverse momentum-spin dynamics of QCD
 - High statistics map of the QCD phase diagram, including search for a possible critical point
 - Probe internal structure of the *most liquid* QGP using fully reconstructed jets and resolved Upsilon states as probes
- **Important machine and detector upgrades underway for BES II (LEReC, iTPC, EPD)**
- **Major detector upgrade underway (sPHENIX)**
- **RHIC enabled R&D to retire major risks of EIC design (CeC, c-BETA, SRF, e-gun)**

Additional slides